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Spatial and temporal trends in the distribution of harbour porpoises, white-beaked dolphins and minke whales off Aberdeenshire (UK), north-western North Sea

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Most North Sea cetacean species are wide-ranging and consequently poorly studied. Spatial and temporal trends in the distribution of the harbour porpoise *Phocoena phocoena*, white-beaked dolphin *Lagenorhynchus albirostris*, and minke whale *Balaenoptera acutorostrata* were assessed at a coastal North Sea study area in Aberdeenshire, Scotland. Between March 1999 and October 2001, cetacean data were collected using both land- and vessel-based survey methods. A total of 174 sightings of these three cetacean species was recorded during approximately 330 h of combined survey effort (228 h land-based and 102 h vessel-based). Harbour porpoises were present throughout the year with peak occurrence during August and September. The presence of white-beaked dolphins and minke whales was strictly seasonal, with a peak in occurrence during August. The fine-scale distribution of all three species varied within the study area, with an apparent preference for sections of coast adjacent to deeper water. Most porpoise calves and juveniles were recorded between June and September, when 35% of harbour porpoise groups contained immature animals. The proportion of calves amongst porpoise sightings was higher during June than any other month. White-beaked dolphin calves were present in 32% of groups, and occurred in all three months that the species was recorded. Group size was higher in white-beaked dolphin pods containing immature animals. The strong seasonality in occurrence of all three species may relate to requirements for breeding habitat, movements of shared prey species and/or inter-specific competition with other species.

INTRODUCTION

Cetaceans inhabiting North Sea waters are vulnerable to a range of anthropogenic threats that include by-catch in fishing operations (Berggren, 1994; Kinze et al., 1997; Vinther, 1999; Kaschner, 2003), pollution (Aguilar & Borrell, 1995), over-fishing of prey species (Evans, 1990; Jackson et al., 2001), and disturbance from sound sources such as shipping, seismic surveys, sonar and acoustic deterrents (Evans, 1996). There is particular concern for species that inhabit coastal areas, where anthropogenic activity tends to be highest (Thompson, 1992).

The occurrence of cetaceans within the western North Sea has primarily been described from data collected concurrently with pelagic seabird surveys and by volunteer networks (Northridge et al., 1995; Reid et al., 2003). Due to the uneven and shifting temporal and spatial pattern of survey effort, such datasets typically enable only low resolution analyses of distribution patterns and may be inadequate as a basis for management of cetacean species (Kaschner, 2003). In addition, a large-scale dedicated cetacean abundance survey was carried out in the North Sea region in July 1994 (Hammond et al., 2002), and provided an estimate of population abundance for various cetacean species.

Detailed year-round data have been collected for only one North Sea cetacean species, the bottlenose dolphin *Tursiops truncatus* (Montagu, 1821) (Wilson, 1995; Stockin et al., 2006). However, several other cetacean species occur within North Sea coastal waters, including the harbour porpoise, *Phocoena phocoena* (Linnaeus, 1758), white-beaked dolphin, *Lagenorhynchus albirostris* (Gray, 1846), and minke whale, *Balaenoptera acutorostrata* (Lacépède, 1804), (Hammond et al., 1995; Northridge et al., 1995; Witte et al., 1998; Reid et al., 2003). In 1994 the absolute abundance of these species within North Sea waters (SCANS blocks C to G) was estimated at approximately 216,000 animals, 8500 animals and 7200 animals respectively (Hammond et al., 2002).

Of the three species, the harbour porpoise has received the most research attention within North Sea waters (e.g. in relation to diet, Santos et al., 2004) and is subject to a high incidence of fishery by-catch in some fisheries (Vinther, 1999; Kaschner, 2003). The designation of marine Special Areas of Conservation (SAC) for the long-term conservation of porpoises, as required for an Annex II species in the EC Habitats and Species Directive (92/43/EEC), is reliant upon detailed data on their population status, distribution and movements. Although some aspects of minke whale biology and distribution have been studied in the northern North

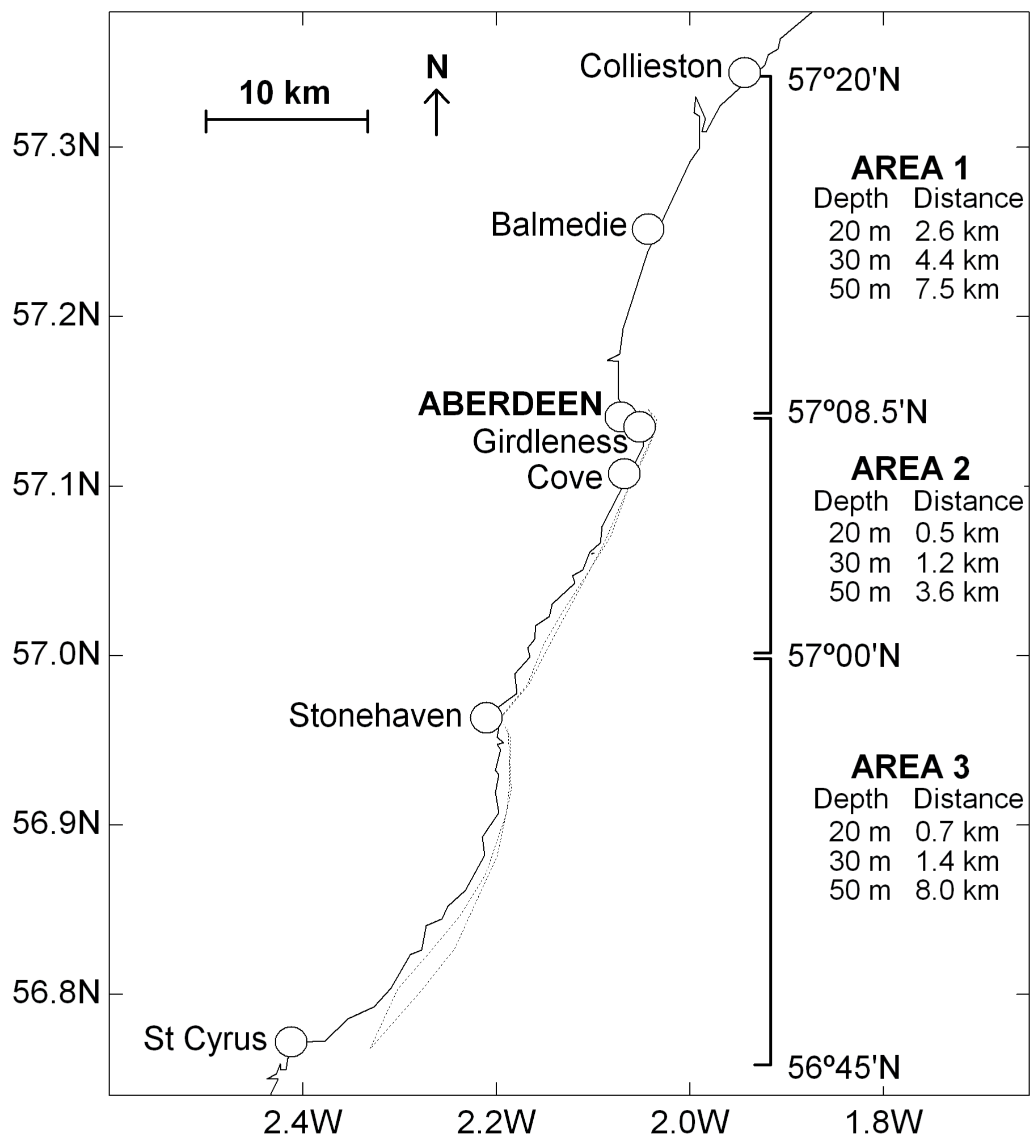

Figure 1. Location of survey sites within the study area, showing typical vessel survey routes (dotted lines) and approximate water depth distributions for each area.

Sea (Øien, 1991; Northridge et al., 1995; Olsen & Holst, 2001), with the exception of dietary studies on stranded animals (Pierce et al., 2004) and the abundance estimate from the SCANS survey (Hammond et al., 2002), very little information is available for this species, or for white-beaked dolphins, in other North Sea regions. The paucity of information on the spatial and seasonal distribution, ecology and population structure of these three species within North Sea waters makes it difficult to estimate the impact of anthropogenic activities and to establish effective mitigation measures where problems exist (Kaschner, 2003).

Here we present the results from a dedicated cetacean survey carried out by experienced voluntary observers within a small coastal study area adjacent to open North Sea waters. Volunteers are frequently used as a practical and cost-effective means of carrying out long-term monitoring of terrestrial mammal and bird populations (Battersby & Greenwood, 2004), and the use of both volunteers and platforms of opportunity is increasingly recognized as an important long-term monitoring method for cetaceans (Leaper et al., 1997; Evans & Hammond, 2004; Thompson et al., 2004). Even if absolute abundance is not measured, such long-term datasets can provide useful indications of changes in population size and distribution. The present study was initiated to focus primarily on bottlenose dolphins (Stockin et al., 2006), but systematic data were also collected

Table 1. *Distribution of survey effort relative to fine-scale survey area, sea state and platform.*

		Land-based survey effort (min)		Vessel-based survey effort (min)	
Area	Total effort (min)	Beaufort sea state 0 to 2	Beaufort sea state 0 to 4	Beaufort sea state 0 to 2	Beaufort sea state 0 to 4
1	8736	3980	7535	328	444
2	9492	3400	5180	3130	4115
3	1545	0	0	1181	1517
Total	19773	7380	12775	4639	6076

Table 2. *Seasonal distribution of survey effort relative to sea state and platform.*

		Land-based survey effort (min)		Vessel-based survey effort (min)	
Survey month	Total effort (min)	Beaufort sea state 0 to 2	Beaufort sea state 0 to 4	Beaufort sea state 0 to 2	Beaufort sea state 0 to 4
January	120	30	120	0	0
February	735	550	735	0	0
March	2290	1010	2095	187	195
April	2945	1575	2625	200	320
May	3273	1045	1460	1274	1813
June	2338	680	1535	580	803
July	1015	165	510	265	505
August	3703	1735	2320	1179	1383
September	1207	320	395	709	812
October	955	120	710	245	245
November	270	150	270	0	0
December	0	0	0	0	0
Total	18851	7380	12775	4639	6076

on the occurrence of all cetacean species with the aim of establishing baseline data on their seasonal distribution and habitat preferences. We describe the occurrence of harbour porpoises, white-beaked dolphins and minke whales in Aberdeenshire waters and analyse variation in their temporal and spatial distribution, group composition and detection rate with respect to sea state and survey platform. We consider the implications of the seasonal occurrence of cetacean species within this coastal site to their management within the larger North Sea region.

MATERIALS AND METHODS

Data were collected using a combination of land- and vessel-based survey methods between March 1999 and October 2001. The survey area spanned the coastal waters of Aberdeenshire, north-east Scotland (UK), between St Cyrus and Collieston (56°45'N to 57°20'N) (Figure 1). The study area could be broadly divided into three different regions based on water depth gradient (Figure 1): (1) shallow (<20 m) sandy bay including Aberdeen harbour; (2) cliff-top coast where deeper water (50 m) occurs only 3.5 km offshore; and (3) similar nearshore environment to Area 2 but with a shallower descent over 8 km linear distance to the 50 m isobath. To ensure standardization and comparability between surveys, only those data collected by seven experienced observers during dedicated marine mammal surveys were utilized for analysis.

Land-based surveys

Between March 1999 and October 2001, land-based surveys were carried out from four main sites within Areas 1 and 2 situated over a linear distance of 28 km: Cove, Girdleness, Aberdeen harbour, Balmedie and Collieston (Figure 1). Surveys were carried out on 127 separate days, producing a total of 213 h effort in visibility ≥1 km and Beaufort sea state ≤4, of which 123 h occurred in Beaufort sea state ≤2 (Tables 1 & 2). Surveys occurred in every calendar month except for December, with most data collected during the spring and summer months (Table 2).

During surveys a continuous scanning methodology (Mann, 1999) was implemented, primarily with the naked eye and supplemented with regular binocular scans (8–10× magnification). The sites were situated at between 15 and 30 m height above sea level, and scans were carried out to the horizon using binoculars. However, most visual effort focused within a 2 km radius of the site. Environmental data (Beaufort wind force and sea state, swell height, precipitation and visibility) were recorded at 15 min intervals throughout each survey, and cetacean data including the species, group size and composition, and behaviour (*ad libitum* sampling (Mann, 1999)) were recorded whenever animals were observed. A best estimate of group size was used for analysis, with 'group' defined as animals engaged in the same activity or travelling in the same direction as others (Shane, 1990). Animals were classified into adults, juveniles and calves where possible, using the following criteria: individuals that appeared full grown were recorded as 'adult', individuals obviously smaller than full-grown (75% adult size) were defined as 'juveniles', and very small animals (often with foetal folds) closely associated with an adult, were classified as 'calves'. During analysis, we also defined the category 'immatures', referring to all juveniles and calves.

Vessel-based surveys

A total of 29 vessel-based surveys was carried out from a 10 m motor vessel (7 knots mean vessel speed, 3.5 m eye-height above sea level) between May 1999 and October 2001. A total of 101 h of survey effort was completed (visibility ≥1 km and Beaufort sea state ≤4), of which 77 h was in conditions of Beaufort sea state ≤2 (Table 1). Vessel-based surveys took place in every calendar month between March and October, with peaks in coverage during May and September (Table 2). No vessel-based surveys could be carried out over the winter due to adverse weather conditions.

Vessel surveys occurred along standard routes, primarily between Stonehaven and Aberdeen (return trip of 48 km), but two surveys ran southwards from Stonehaven to St Cyrus (return trip of 50 km) (Figure 1). Survey routes were not pre-determined with fixed waypoints, but normally ran parallel to the coastline within 1.5 km of the coast (where the probability of sighting bottlenose dolphins was highest), with some variation depending on prevailing weather conditions. The use of such methods to estimate relative abundance is well established (Leaper et al., 1997; Evans & Hammond, 2004; MacLeod C.D. et al., 2004; Thompson et al., 2004). The opportunity was taken on four occasions in calm weather to extend the survey route to 3.5 km from the coast to sample the cetacean community further offshore.

A minimum of two experienced observers (and up to six additional observers) was onboard during each survey, and watches rotated between the port and starboard sides of the vessel. Methodology comprised continuous scanning (Mann, 1999) with the naked eye and binoculars (8–10× magnification). Vessel surveys lasted 3–5 h, and

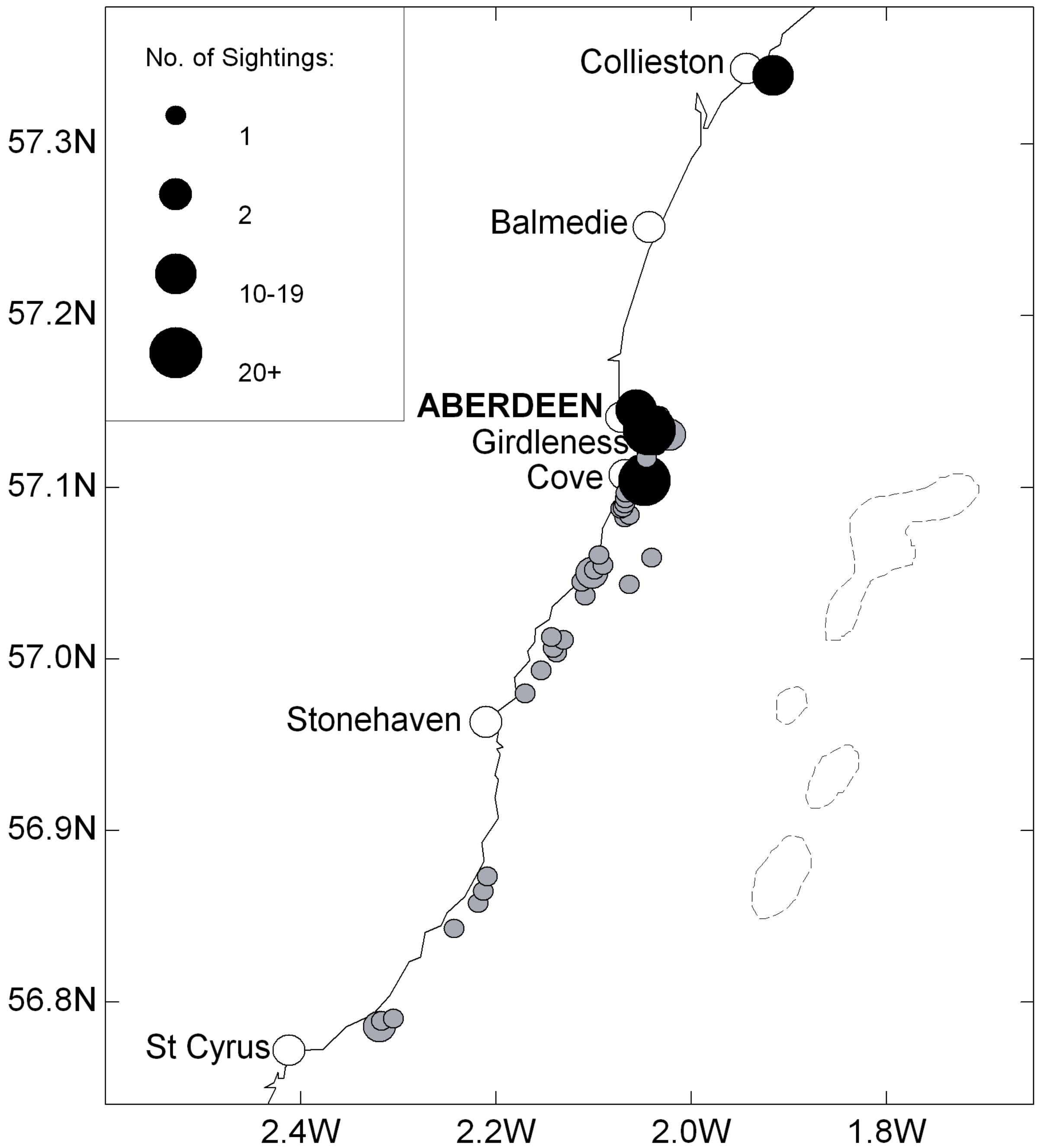

Figure 2. Distribution of harbour porpoise sightings (N=122) made during land-based (black symbols) and vessel-based (grey symbols) surveys.

Table 3. *Sighting rates of harbour porpoise* Phocoena phocoena *and white-beaked dolphins* Lagenorhynchus albirostris *by fine-scale study area.*

	P. phocoena SPUE/IPUE[1]			*L. albirostris* SPUE/IPUE[2]		
Area	Land	Vessel	Pooled	Land	Vessel	Pooled
1	0.09/0.20	0.37/0.73	0.11/0.24	0/0	0/0	0/0
2	0.76/1.84	0.69/1.32	0.73/1.59	0.31/2.05	0.15/0.69	0.24/1.45
3	—	0.51/0.91	0.51/0.91	—	0.40/1.78	0.40/1.78
Total	0.40/0.95	0.62/1.18	0.48/1.04	0.13/0.83	0.20/0.91	0.15/0.86

[1], Data at Beaufort sea state 0–2; [2], data at Beaufort sea state 0–4. Refer to Table 1; SPUE, sightings rate per unit effort; IPUE, individuals per unit effort.

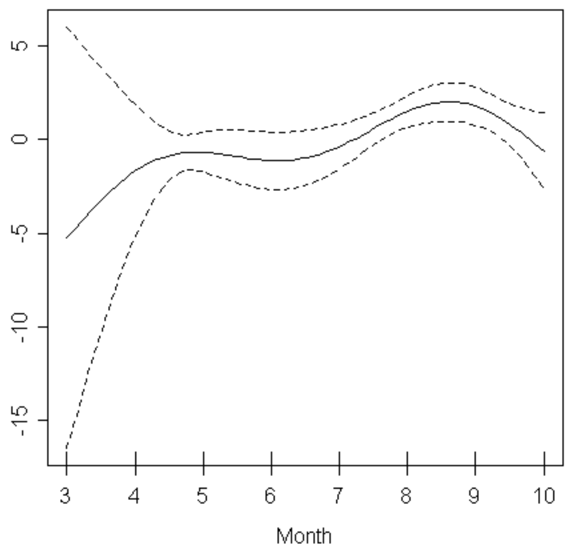

Figure 3. The fitted 'smoother' curves (with 95% confidence limits) depicting the effect of month on porpoise presence during vessel surveys, indicating peak occurrence in August to September.

both vessel position (using Global Positioning System) and environmental data (as above) were recorded at 15 min intervals. Cetacean data (species, position, group size, composition and behaviour) were collected whenever animals were observed.

Calculation of sighting rates

For analysis, we excluded data collected in poor visibility (<1 km). Since the amount of data collected in some Beaufort sea states was small, our dataset was insufficient to calculate meaningful species-specific correction factors to compensate for the effect of sea state on detection (Palka, 1996). Instead, we followed the criteria utilized by Hammond et al. (2002), and eliminated all data collected in Beaufort sea states of greater than 2 for harbour porpoise and minke whale analyses, and utilized only data collected in Beaufort sea state 0 to 4 for white-beaked dolphins. Responsive movement of cetacean species to boats may also influence the calculation of sighting rates for vessel-based surveys (Palka & Hammond, 2001). Therefore land- and vessel-based survey data were analysed separately.

Each land- and vessel-based survey was usually coded in successive 15 min periods (effort sample units), based on the sampling interval of associated environmental data. For land-based surveys 169 out of 242 effort sample units at Beaufort 2 or less lasted 15 min (range: 10–180 min). For vessel-based surveys, 195 out of 326 effort sample units at Beaufort 2 or less lasted 15 min (range: 2–35 min). For the extended data set (Beaufort 4 or less), 336 out of 448 land-based effort sample units lasted 15 min (range: 5–270 min), while 249 out of 430 vessel-based effort sample units lasted 15 min (range: 2–35 min).

We derived two measures of sighting rate. The sightings rate per unit effort (SPUE) is the number of sightings per 60 min search effort, while individuals per unit effort (IPUE) is the number of animals seen per 60 min search time. Both provide an index of relative abundance (Northridge et al., 1995; Reid et al., 2003). During the analyses by season, data were grouped as follows: winter (December to February), spring (March to May), summer (June to August) and autumn (September to November).

Analysis of factors affecting cetacean sighting rates

To examine patterns in occurrence, and to identify which environmental variables (visibility, sea state, fine-scale survey area and month) best explained the observed cetacean occurrences, binomial generalized additive models (GAM) were used, fitted using Brodgar software (www.brodgar.com). Presence/absence for a species was chosen as the binary response variable with a logit link function. Explanatory variables were fitted in different combinations (variously as smoothers, linear terms, and factors) and the best model selected based on the Akaike information criterion (AIC).

Additionally, to analyse variation in cetacean occurrence, group size and presence of calves, we used chi-squared,

Table 4. *Monthly sighting rates of harbour porpoise* Phocoena phocoena *and white-beaked dolphins* Lagenorhynchus albirostris.

	P. phocoena SPUE/IPUE[1]			*L. albirostris* SPUE/IPUE[2]		
Month	Land	Vessel	Pooled	Land	Vessel	Pooled
January	0/0	—	0/0	0/0	—	0/0
February	0/0	—	0/0	0/0	—	0/0
March	0.36/0.53	0/0	0.30/0.45	0/0	0/0	0/0
April	0.15/0.38	0/0	0.14/0.34	0/0	0/0	0/0
May	0.23/0.23	0.24/0.38	0.23/0.31	0/0	0/0	0/0
June	0.09/0.18	0/0	0.05/0.10	0.20/0.98	0.30/1.34	0.23/1.10
July	0/0	0.23/0.45	0.14/0.28	0/0	0.48/2.50	0.24/1.24
August	0.97/2.80	1.32/2.60	1.11/2.72	0.57/3.93	0.52/2.30	0.55/3.32
September	0.94/1.69	1.27/2.37	1.17/2.16	0/0	0/0	0/0
October	0/0	0.24/0.49	0.16/0.33	0/0	0/0	0/0
November	0.40/0.80	—	0.40/0.80	0/0	—	0/0
December	—	—	—	—	—	—
Total	0.40/0.95	0.62/1.18	0.48/1.04	0.13/0.83	0.20/0.91	0.15/0.86

[1], Data at Beaufort sea state 0–2; [2], data at Beaufort sea state 0–4. Refer to Table 2; SPUE, sightings rate per unit effort; IPUE, individulas per unit effort.

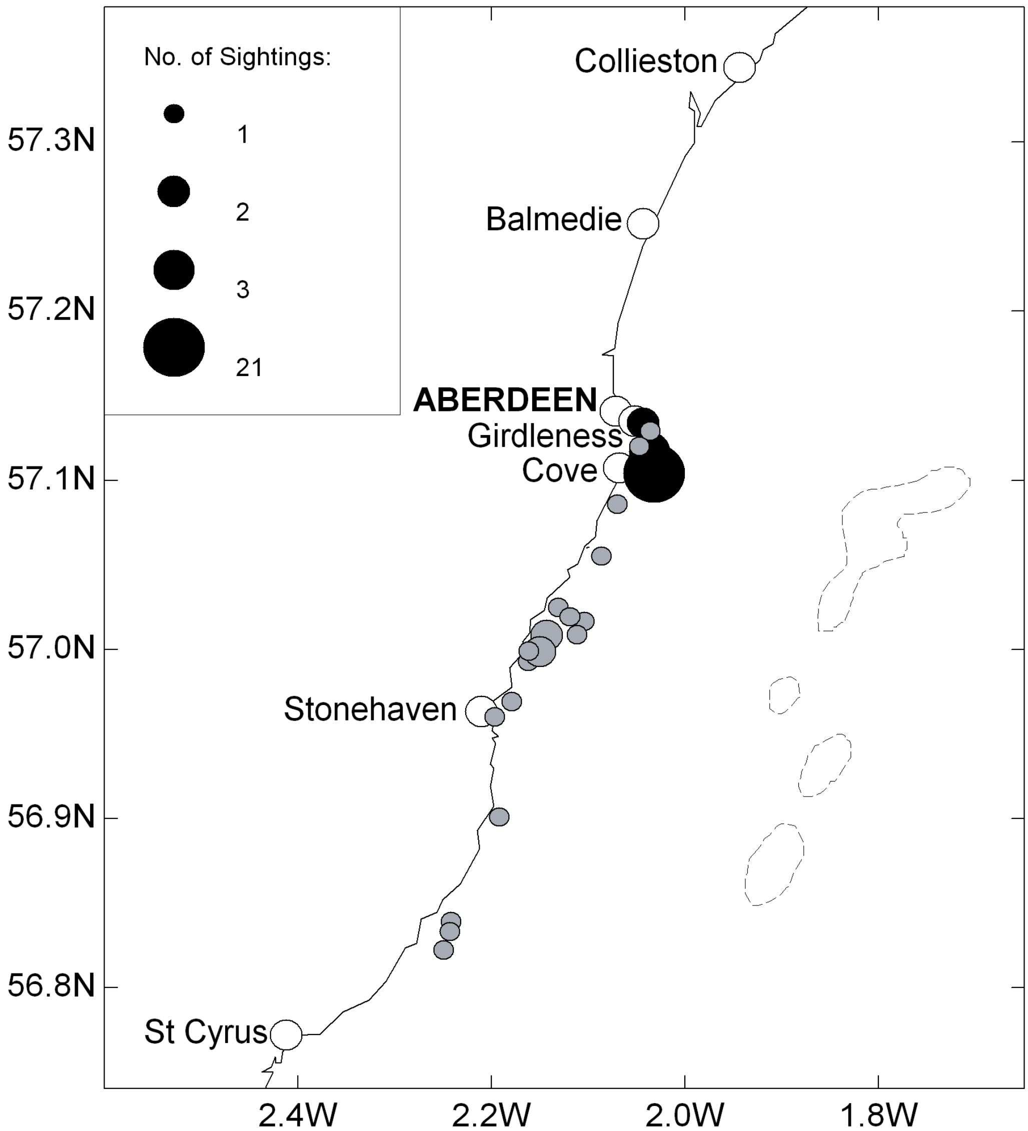

Figure 4. Distribution of white-beaked dolphin sightings (N=47) made during land-based (black symbols) and vessel-based (grey symbols) surveys.

Kruskal–Wallis and Mann–Whitney *U*-tests, since Kolmogorov–Smirnov goodness-of-fit tests indicated the data to be non-normal. For univariate analyses of cetacean occurrence, only data collected at Beaufort sea state ≤2 (harbour porpoise and minke whales), or Beaufort sea state ≤4 (white-beaked dolphins) were utilized (see calculation of sighting rates). Season (as defined above) was used rather than month in chi-squared analyses since the latter would have generated too many groups with relatively small sample sizes. Analyses were carried out separately for data from land- and vessel-based surveys, except where otherwise specified.

RESULTS

A combined total of 330 h land- and vessel-based survey effort was collected during the study, including 314 h in good visibility (≥1 km) and Beaufort sea state ≤4. The temporal survey coverage was similar for both land- and vessel-based surveys, with highest effort between March and September (Table 2). However, the spatial coverage varied between land- and vessel-based methods, with both producing good coverage in Area 2, but most land-based surveys occurring in Area 1 and vessel-based surveys producing the only coverage in Area 3 (Table 1).

Harbour porpoise

A total of 122 harbour porpoise sightings was recorded during the study, of which 73 occurred during land-based watches and 40 during vessel surveys. The sightings were distributed across the entire study area, at all locations with survey effort (Figure 2). Of the total sightings, 97 (49 land-based and 48 vessel-based) occurred in Beaufort sea state ≤2 and were included in calculations of relative abundance.

The mean overall SPUE for porpoises in the Aberdeenshire region using the pooled dataset was 0.48, with a mean IPUE of 1.04 animals (Table 3). The IPUE was highest in Area 2, where the majority of sightings occurred off Cove and Girdleness, and lowest in Area 1 (Table 3). Chi-squared tests indicate that porpoises were sighted more frequently in Area 2 than in Area 1 during land-based surveys (χ^2=9.43, df=1, P=0.001) although there was no area effect on sightings frequency from vessel-based surveys (χ^2=2.92, df=2, P=0.116).

Table 5. *Harbour porpoise,* Phocoena phocoena, *calf ratios (see Sonntag et al., 1999) for combined land- and vessel-based survey data.*

		Calves		Juveniles		Total immature	
Month	Total number of porpoises/groups	% of total	% of pods with	% of total	% of pods with	% of total	% of pods with
January	0/0	—	—	—	—	—	—
February	1/1	0.0	0.0	0.0	0.0	0.0	0.0
March	10/7	0.0	0.0	20.0	28.6	20.0	28.6
April	14/6	0.0	0.0	0.0	0.0	0.0	0.0
May	13/10	0.0	0.0	7.7	10.0	7.7	10.0
June	14/7	21.4	42.9	0.0	0.0	21.4	42.9
July	14/6	0.0	0.0	7.1	16.7	7.1	16.7
August	107/51	0.9	2.0	18.7	35.3	19.6	37.3
September	35/19	8.6	15.8	11.4	21.1	20.0	31.6
October	12/7	0.0	0.0	0.0	0.0	0.0	0.0
November	2/1	0.0	0.0	0.0	0.0	0.0	0.0
December	0/0	—	—	—	—	—	—
Total	222/115	3.2	6.1	12.6	22.6	15.8	27.8

The SPUE and IPUE varied between months with a peak in the relative abundance of porpoises during August and September (Table 4). This peak was observed in both land- and vessel-based surveys (Table 4).

The GAM results for porpoise presence during vessel surveys indicated that the best model included effects of month (smoother with 4 df, χ^2=27.54, P<0.001), sea state (linear, t = −1.92, P=0.055), and area (as factor, P>0.05). The effect of duration of the effort sample unit was not significant and was not included in the best model. The smoother fitted to describe the effect of month suggests that peak porpoise presence occurs in August and September (Figure 3). The model for land-based surveys included effects of the duration of the effort sample unit (smoother with 4 df, χ^2=22.54, P<0.001), sea state (linear, t =−3.29, P=0.001), month (smoother with 4 df, χ^2=6.63, P=0.157) and area (as factor, P=0.114). Note that the area effect is not individually significant in either model while the effect of month is non-significant in the model for land-based surveys.

There was no significant difference in the median group size of porpoises between months (combined data for all surveys; Kruskal–Wallis test, H=10.5, df=9, P=0.31). The overall mean group size was 2.08 animals (N=122, SD=1.99, range=1–20), and most sightings comprised single animals (N=52). The majority of immature animals (N=35) were recorded between June and September, when 35.4% (N=82) of harbour porpoise groups contained young animals (Table 5). Animals identified as calves were only sighted on seven occasions (N=7), and the proportion of porpoise groups containing calves peaked in June, with smaller numbers during August and September (Table 5). Animals identified as juveniles (N=28) were sighted on 26 occasions, of which 24 sightings occurred in Beaufort sea state ≤2 and were suitable for chi-squared statistical analysis. Using combined land-

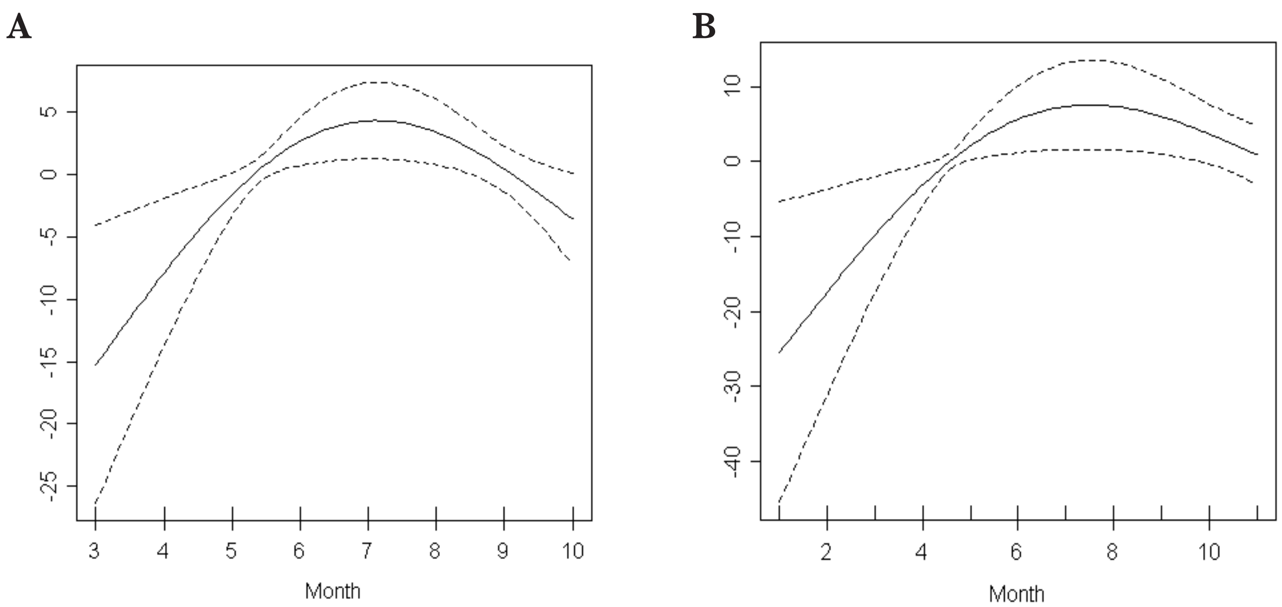

Figure 5. The fitted 'smoother' curves (with 95% confidence limits) depicting the effect of month on white-beaked dolphin presence during (A) vessel surveys and (B) land-based surveys, indicating peak occurrence in July to August.

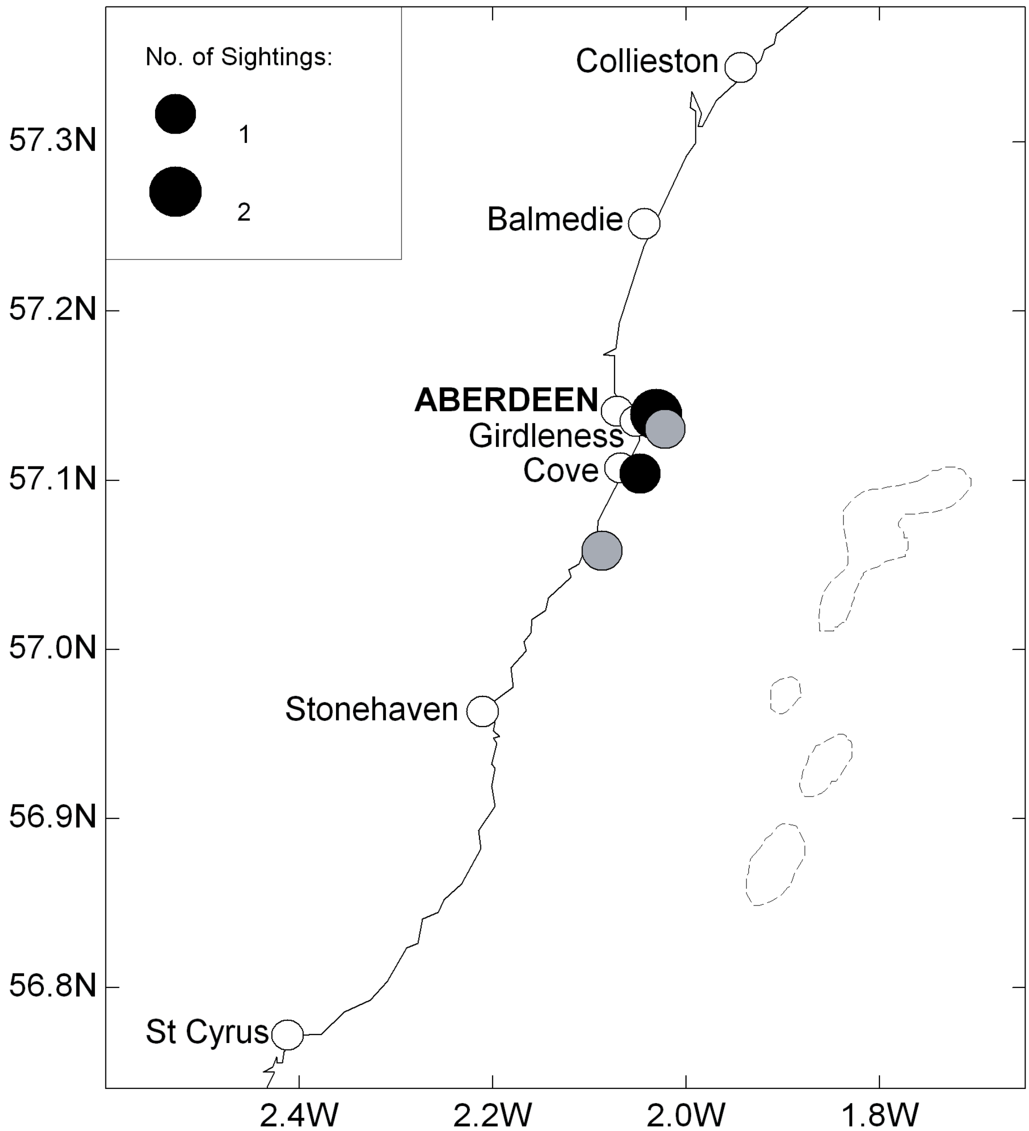

Figure 6. Distribution of minke whale sightings (N=5) made during land-based (black symbols) and vessel-based (grey symbols) surveys.

and vessel-based survey data (due to small sample size), the presence of juvenile porpoises was significantly related to fine-scale area (χ^2=16.46, df=2, P<0.001), with more juvenile porpoises than expected observed in Area 2. The presence of juvenile porpoises was also higher in summer than in spring or autumn (winter data were excluded due to small sample size, although no juveniles were seen in winter, χ^2=9.87, df=2, P=0.007), and the summer months thus appear to represent a seasonal peak in occurrence of all porpoise age-classes.

White-beaked dolphin

Throughout the study, a total of 47 white-beaked dolphin sightings was recorded, comprising 27 from land- and 20 during vessel-based surveys. Most white-beaked dolphins were sighted in Area 2 along the Cove to Girdleness coast (Figure 4). A chi-squared test confirms that the incidence of white-beaked dolphins was significantly higher in Area 2 than in Area 1 during the land-based surveys (χ^2=21.99, df=1, P<0.001). However, there was no significant difference between areas in the incidence of sightings during the vessel-based surveys χ^2=3.74, df=2, P=0.077). The highest relative abundance of white-beaked dolphins occurred in Area 3, where a mean SPUE of 0.40 and an IPUE of 1.78 animals was recorded (Table 3). However, we note that Area 3 received exclusively vessel-based coverage.

White-beaked dolphins were recorded only between June and August (Table 4), despite good coverage for both land- and vessel-based surveys in most other months (Table 2). The SPUE was comparable between land- and vessel-based surveys during June and August, but sightings were exclusively vessel-based during July. The SPUE for land, vessel and pooled datasets was higher during August than other months (Table 4).

The best GAM model for white-beaked dolphin presence during vessel surveys included effects of month (smoother with 2 df, χ^2=7.96, P=0.019), duration of the effort sample unit (smoother with 2 df, χ^2=1.37, P=0.5) and sea state (linear, t=–2.64, P=0.008), although the duration effect was not individually statistically significant. The results indicate a decline in detectability in rougher seas. The fitted smoother for the effect of month indicates that, once other effects have been accounted for, presence peaks in July (Figure 5A). For land-based survey data, the best GAM included effects of month (smoother with 2 df, χ^2=6.48, *P*=0.039) and sea state (linear, *t* =−1.48, *P*=0.139), although only month has a significant effect. The shape of the smoother indicates peak presence in July to August (Figure 5B).

White-beaked dolphins were recorded in groups of between one and 32 animals, with a mean (for combined surveys) of 5.7 individuals (N=47, SD=5.9). There was no significant difference in the mean group size between the three months that dolphins were recorded (Kruskal–Wallis test, H=1.44, df=2, *P*=0.49). Immature animals accounted for 19% of the total white-beaked dolphins (N=44) observed off Aberdeenshire. Immatures were recorded in all three months that white-beaked dolphins were present, with 32% of groups containing calves and 48% of all pods containing calves and/or juveniles. The mean group size of white-beaked dolphins was significantly higher (Mann–Whitney *U*-test, U=90, *P*<0.001) when pods contained immature animals ($\bar{x}$ =7.9, SD=7.3, N=21) than in adult only pods ($\bar{x}$ =3.4, SD=2.2, N=23).

Minke whale

A total of five minke whale sightings was recorded over the survey period, three during land-based surveys and two during vessel-based surveys. All involved solitary individuals, of which three were adults and two were juveniles. Minke whales were observed only in a relatively small spatial region within Area 2 (Figure 6), producing a very similar SPUE and IPUE of 0.05 and 0.04 in Area 2 for land- and vessel-based surveys respectively. Minke whales had an overall SPUE/IPUE of 0.02 for the pooled datasets in the entire Aberdeenshire region. The sightings all occurred during August, producing a SPUE and IPUE of 0.10 for that month in all datasets.

DISCUSSION

The data presented here confirm the findings of previous larger spatial-scale survey work that suggest the harbour porpoise and white-beaked dolphin to be regular inhabitants of the North Sea (Northridge et al., 1995; Hammond et al., 2002; Reid et al., 2003). Additionally, the present data demonstrate the regular occurrence of these species within coastal Aberdeenshire waters. Minke whales were also observed, although infrequently. Although inappropriate to estimate absolute abundance, the use of volunteer sightings data and non-random survey designs can still provide indices of relative abundance that are useful for the long-term monitoring of cetacean populations (Northridge et al., 1995, 1997; Leaper et al., 1997; Evans & Hammond, 2004; MacLeod C.D. et al., 2004; Thompson et al., 2004).

Variation in survey effort can be effectively addressed by quantifying the effort to provide useful data on the spatio-temporal distribution of cetaceans (Northridge et al., 1995, 1997; Evans & Hammond, 2004). During this study, the spatial and temporal variation in survey effort was accounted for by: (a) using only data from effort-related surveys; (b) incorporating the levels of effort into an index of relative abundance; and (c) including duration of the effort sample unit as a potential explanatory factor in the GAMs. Variation in results due to platform type was also a consideration during this study, since the data were collected during both land- and vessel-based surveys. The observation range is likely to be greater and less dependent on sea state during land-based surveys, while vessel-based surveys traverse a greater spatial area and include greater fine-scale heterogeneity in habitat. Vessel-based surveys may also evoke negative or positive responsive movement in cetaceans that can influence the animals recorded during the survey (Palka & Hammond, 2001). Although data were collected from both land and vessel during the study, the results from each were analysed separately and together as a pooled dataset, and were generally similar. For example, in Area 2 where the levels of land- and vessel-based survey effort were high and comparable, both platform types produced a similar relative abundance for all three species.

Porpoises and white-beaked dolphins showed similarities in their fine-scale spatial distribution within Aberdeenshire coastal waters, being sighted least often in shallow, sloped waters, and most often in areas where the relatively deeper 20 m isobath occurred adjacent to the coast. The regularity of white-beaked dolphin sightings observed within this coastal area is comparatively higher than reported from other North Sea regions (Reid et al., 2003), and highlights Aberdeenshire as an important area for this poorly studied species. It is notable that the fine-scale distribution of these species within the study area contrasts with that of the bottlenose dolphin, which occurs most frequently within Area 1 (Stockin et al., 2006). This difference in habitat utilization may reflect variation in ecological parameters such as water depth and prey distribution, but could also conceivably arise from inter-specific interactions with bottlenose dolphins and/or from differing reactions to anthropogenic influences including shipping noise and dredging (Evans, 1996) associated with the commercial port of Aberdeen harbour situated within Area 1. Although Aberdeen harbour lies close to the border between Areas 1 and 2, its particular influence on cetacean occurrence within Area 1 should not be underestimated. The harbour lies at the mouth of the River Dee, an established salmon river, and bottlenose dolphins utilize the spatially distinct harbour region as a key feeding site in clear preference to nearby adjacent sites such as Girdleness (Stockin et al., 2006). Vessel traffic also approaches and departs the harbour at an angle perpendicular to the coast, and therefore has a disproportionately larger potential impact on Area 1.

Although the harbour porpoise occurs for at least most of the year in Aberdeenshire waters, sightings show a seasonal increase between July and October. The seasonality of white-beaked dolphins was more marked, with a clear peak in relative abundance during August. Minke whales were only observed during August. The summer increase in occurrence of these three species is even more striking when contrasted with the marked winter/spring peak relative abundance of bottlenose dolphins in Aberdeenshire waters (Stockin et al., 2006). It is currently unclear whether porpoises, white-beaked dolphins and minke whales are moving into Aberdeenshire waters from adjacent coastal regions during the summer months, or whether the movements are inshore–offshore (Northridge et al., 1995). There are a number of potential explanations for the seasonal distribution of these species, including requirement for suitable calving conditions, the movement of prey species and inter-specific competition with other cetacean species.

Harbour porpoise calves were recorded only between June and August, which corresponds with the known calving period of this species throughout North Sea waters (Evans, 1991; Lockyer, 1995). Calves comprised 3.2% of the total porpoises recorded during the study (Table 5), which is similar to the 3.3% calves calculated for this area during the SCANS survey (Sonntag et al., 1999). This percentage is certainly not high enough to indicate the use of Aberdeenshire as a preferred calving ground, but nevertheless it does indicate that some porpoises utilize this area to breed. White-beaked dolphins also calve during the summer months (Kinze et al., 1997), and Evans (1991) suggests that births occur offshore in the northern North Sea. Our results do not conflict with this theory, since groups of white-beaked dolphins arriving in Aberdeenshire waters in June already included small calves. However, calves were continually sighted throughout July and August indicating that some calving probably also occurs within coastal waters.

The movement of prey may also explain the seasonality of cetaceans within the coastal site, since porpoises, white-beaked dolphins and minke whales feed upon a wide range of prey species, which vary in occurrence both temporally and spatially (Evans, 1990; Aarefjord & Bjørge, 1995; Haug et al., 1996; Pierce et al., 2004; Santos et al., 2004). Although North Sea porpoises take a wide diversity of clupeids and gadids (Aarefjord & Bjørge, 1995; Martin, 1995), sandeels *Ammodytes* spp., and whiting *Merlangius merlangus*, appear to be their primary prey species off the east coast of Scotland (Santos et al., 2004). Minke whales also take a range of species in Scottish waters but predominantly sandeels (Olsen & Holst, 2001; Pierce et al., 2004), while the main prey of white-beaked dolphins stranded in Scottish waters is whiting (Santos et al., 1994). It is clear that these three cetacean species share a number of common prey in North Sea waters, and since many clupeids and gadids also feed upon sandeels (Temming et al., 2004) there are both direct and indirect potential food-chain links between the movement of prey species and observed cetacean distribution. Changes in the distribution and abundance of porpoises, white-beaked dolphins and minke whales have been related to that of preferred prey species in other regions (Evans, 1990; Brodie, 1995; Trippel et al., 1999; Macleod K. et al., 2004). Within Aberdeenshire, mackerel in particular are known to move inshore during the summer months (Coull et al., 1998), and anecdotal evidence from local fishermen suggests that large numbers of mackerel are present within Area 2 coastal waters during July (Brian Bartlett, personal communication) when porpoise and white-beaked dolphin occurrence increases.

We conclude that the increased relative abundance of porpoises, white-beaked dolphins and minke whales in coastal waters during the summer months might be the result of a combination of factors, including the distribution of prey species, preferred habitat utilization of sheltered waters during the calving season, and a seasonal increase in energetic demand related to calving, lactation and/or seasonal migration (Lockyer, 1987; Bernard & Hohn, 1989; Recchia & Read, 1989). The possibility of inter-specific competition with bottlenose dolphins cannot be excluded as a potential explanation for the variation in porpoise and white-beaked dolphin sightings. However, bottlenose dolphins are more frequently observed in shallower waters (Stockin et al., 2006) and feed on different prey species from the other Aberdeenshire cetacean species (Santos et al., 2001). Bottlenose dolphins are known to interact violently with porpoises and resulting avoidance behaviour by porpoises could result in temporal and/or spatial habitat segregation between these species (Thompson et al., 2004).

The results of this survey work provide insight on the temporal habitat utilization and relative abundance of species within a cetacean community, and additionally emphasize the value of using volunteers to conduct long-term monitoring of cetacean populations, something long recognized by those organizations surveying UK terrestrial mammals and birds (Battersby & Greenwood, 2004). The continued monitoring of cetacean species is important for establishing conservation priorities, assessing anthropogenic impacts and measuring the effectiveness of management plans. Such data are especially important when information on seasonal movements, and identification of feeding and breeding/nursery areas are required, such as for the conservation of harbour porpoises, one of the two cetacean species for which member states are required to establish Special Areas of Conservation (SACs) under the EU Habitats Directive (92/43/EEC).

The marked seasonality in relative abundance of cetacean species described here for North Sea coastal waters, is also relevant to the development of effective mitigation measures against anthropogenic threats. For example, understanding of the temporal and spatial distribution of harbour porpoises is essential to determine when animals might come into contact with particular fisheries and to mitigate against potential by-catch (Brodie, 1995; Vinther, 1999; Murray et al., 2000). Although there is evidence for incidental capture of white-beaked dolphins during North Sea trawl fisheries (Kinze et al., 1997) there are few data available on the extent of this by-catch (Kaschner, 2003), and the conservation status of both the white-beaked dolphin and the minke whale within North Sea waters is currently unknown. Baseline data on the seasonal movements and occurrence of these species within North Sea regions are essential for an understanding of their conservation threats and future management.

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